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AVENTURINE GLAZES

BY

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

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STUDIES IN AVENTURINE GLAZES.

I

Introduction

Of all the types of glazes, probably the most beautiful and yet the most difficult to produce are the crystalline glazes. There has been very little technical research done on this subject and undoubtedly if more work were done on the subject and more information were available, crystalline glazes could be produced and controlled as easily as other glazes. The glaze composition, the heat treatment of the glaze, and the body composition, are factors which have to be studied for each particular glaze.

There are two types of crystalline glazes¹:- The first type, the macro-crystalline glazes, includes the aventurine glaze, sometimes called "goldstone" or "tiger eye". In this type the crystals separate out of the molten matrix on cooling of a size readily visible to the naked eye. The second type, the micro-crystalline glazes, includes some of the mott glazes. In this type, the entire mass crystallizes. For developing aventurine glazes, Stull recommends applying metallic oxides to the body and covering this with a boric acid glaze. When the glaze fuses and becomes fluid, it takes part of the metallic oxide into solution and, if enough of it is dissolved, the glaze becomes supersaturated and crystals separate out on cooling.

Mellor² has given a good explanation of the formation of crystalline glazes by comparing the molten matrix with ordinary

¹ R. T. Stull "Notes on the Production of Crystalline Glazes".
Trans. Am. Cer. Soc. Vol. VII, 1904 p.186

²² J. W. Mellor "Crystallization in Pottery".
Trans. Eng. Cer. Soc. Vol. IV, 1902 p.52

solutions as follows: "The molecules of the solution resist crystallization and some crystallizing force is required to start crystallization." Ostwald³ states that it is only necessary to have one millionth part of a milligram in a solution of sodium chloride to overcome the passive resistance of the molecules and start crystallization of the sodium chloride. Stull⁴, in comparing the crystallizing tendencies of various oxides draws the following conclusions:-

I. The strongest crystallizing tendencies are given to glazes by those chemical elements of low atomic weight whose oxides go to make up the RO , such as sodium, potassium, magnesium, calcium, manganese, iron zinc, etc.

II. Those metals of high atomic weight, such as barium, lead, etc., seem to impart a glossy nature to silicates when used in sufficient quantities, which is unfavorable to crystallization.

III. Those chemical elements of higher atomic weight whose oxides make the acid portion of a glaze such as silicon, titanium, phosphorus, etc., produce the best crystallizing agents, while those of lower atomic weight, as for example, boron, having an atomic weight of 11, impart a fluidity and brilliancy to a glaze which is detrimental to crystallization.

IV. The introduction of an R_2O_3 materially assists crystallization in some cases, while in others it is detrimental to it,

³ Zeit. Phys. Chem. 1897, 22, 289.

⁴ Ibid 1. Vol. VI., p. 188.

⁵The name "Aventurine" as applied to glazes, originated from its similarity to certain types of quartz and feldspar spangled with scales of mica, hematite or gothite, They give off fire-like reflections when held in a bright light and are known as aventurine feldspar and aventurine quartz.

Wohler⁶ produced glazes having a similar appearance in 1849. Wartha⁷ obtained an aventurine effect by first applying an engobe of iron or uranium oxide and then covering the same with a borax glaze.

Aventurine glazes are produced by mixtures in which there is an excess of metallic oxides which go into solution. The glaze matrix becomes saturated with the metallic oxide, and on cooling, the solvent capacity of the glaze reaches a maximum, the glaze becomes supersaturated, and the excess gradually separates out in thin, plate-like crystals. The metallic oxides generally used in aventurine glazes are those of iron, chromium, and sometimes copper. Mellor⁸ states that aventurine glazes are more easily obtained on red tile than on white tile. This is probably due to the fact that the glaze dissolves some iron oxide from the body and aids in saturating the glaze. Stull⁹ advises the use of vitrified bodies which have been biscuited at a temperature of two or three cones higher than that of the glaze.

Zimmer¹⁰ states that it is necessary to have; 1st, a continuously oxidizing fire; 2nd, a gradually increasing temperature;

⁵ H. G. Schurecht -- Journal Amer. Cer. Soc., Vol. 3, No. 12

⁶ Thomind, Ztg., 1896, p. 219.

December, 1920.

⁷ Ibid, 1890 p. 170.

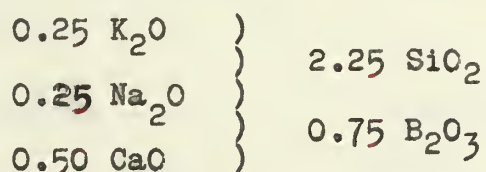
⁸ Zeit. Phys. Chem. 1897, 22, 289.

⁹ Ibid 1.

¹⁰ W. H. Zimmer, "Crystallized Glazes". Trans. Am. Cer. Soc. Vol. 14-1912.

3rd, a gradually decreasing temperature; and 4th, exclusion of Al_2O_3 from the glaze. The rates of crystallization of the different glazes vary so much with the temperature that the rate of cooling after burning must be regulated to suit the glaze. Correct cooling is of as much importance as is correct composition. The purpose of the slowly cooling fire is to give the crystals time to grow.

Most writers are of the opinion that the "aventurine effect" is best produced by introducing iron in a suitable form into a properly constituted glaze. Mackler ¹¹ determined the effect of increasing the iron oxide content in glazes of the cone 09 type and found that when 35 parts of iron oxide were added to 100 parts of glaze, he obtained an aventurine effect, but the color of the glaze was too dark, due to the reduction of the iron oxide to the ferrous condition. He, therefore, tried 20 per cent of finely ground metallic iron and obtained a transparent yellow glaze with many gold-like crystals. The glaze used by him corresponded to the following formula:-



Patrik: ¹² produced artificial crystals of hematite by melting a mixture of iron sulphate and sodium chloride and dissolving in water. Crystals 1 to 2 mm. in diameter were produced in this manner. These crystals are not easily dissolved in the glaze melt

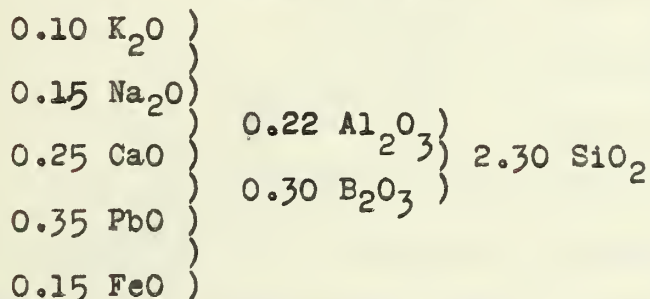
¹¹ Thonind, Zeitg., 1896, p. 219.

¹² Ibid 11, 1896, p. 275.

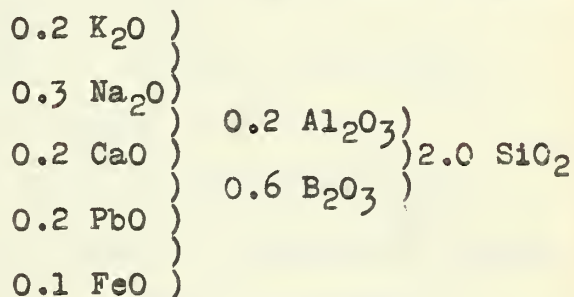
and when introduced into a glaze appear as bright scales similar to aventurine glazes.

The following are two formulae for aventurine glazes submitted by Parmelee¹³ and reported as giving good golstone glazes:-

Cone 2 glaze



Fritt for cone 2 glaze



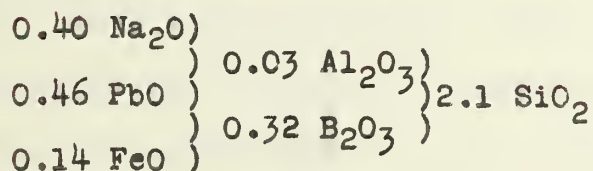
Batch Weights

Fritt	141
Whiting	15
White lead	65
China clay	31
Flint	64
Red iron oxide	8

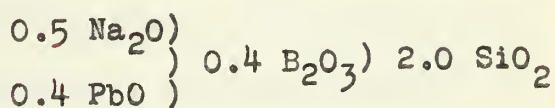
Batch weights for fritt

Feldspar	111
Borax	115
Whiting	20
White lead	52
Flint	48
Red Iron oxide	8

Cone 09 glaze



Fritt for Cone 09 glaze



Batch Weights

Fritt	220
Red lead	32
Red iron oxide	5
Ball clay	8
Flint	24

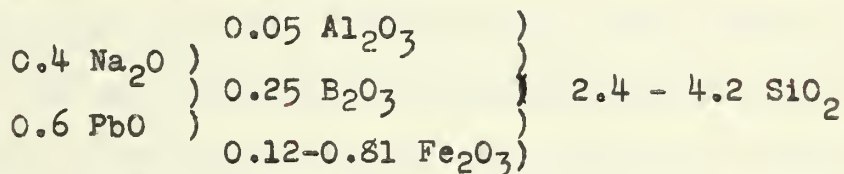
Batch weights for fritt

Borax	76
Sodium carbonate	32
Red lead	91
Red iron oxide	8
Flint	120

II

Discussion of Previous Investigations.

¹⁴In experiments conducted by the Bureau of Mines, the effect of varying iron oxide and silica was studied between the following limits in a cone 4 aventurine glaze:



A. Summary of Work done by the U.S. Bureau of Mines

1. Within the foregoing experimental limits aventurine glazes were obtained with more than 0.41 Fe_2O_3 in glazes containing 2.4 SiO_2 , and with more than 0.58 Fe_2O_3 in glazes containing 4.2 SiO_2 .

2. Glazes with 0.41 to 0.73 Fe_2O_3 vary in color from red to black according to kiln conditions, red being produced under oxidizing conditions and black under reducing conditions.

3. With reducing conditions the glazes high in iron become a dull black with a metallic lustre. By applying a thin coating of accone 02 lead glaze on the surface of such a glaze and firing in an oxidizing atmosphere, a maroon effect is obtained.

4. Increasing the iron content increases the size and number of crystals and also the refractoriness of the glazes.

B. Work done by Nathan Bromberg on Thesis for B.S. Degree in Ceramic Engineering, University of Illinois, 1915.

The purpose of this study was to develop aventurine glazes which would mature at cone 010 (950°C), cone 1 (1150°C) and cone 5 (1230°C). The field to be investigated was determined on,

and a rectangular diagram drawn so as to include all the variations desired.

Bromberg's General Conclusions.

From the results of the foregoing studies, the following conclusions may be drawn:

1. The formation of crystals depends upon the slow cooling of the glaze. As each glaze has a different rate of crystallization at each temperature, the cooling curve for each glaze should be determined individually.

2. The amount of Fe_2O_3 necessary for the formation of aventurine crystals depends upon the glaze and may vary from 0.25 to 0.6 molecules.

3. Increasing the Na_2O content increases crystallization.

4. Aventurine crystals may be formed in the presence of .2 molecules of Al_2O_3 .

5. Aventurine crystals may be formed in the presence of CaO even when there is as much as 0.4 molecule present.

6. Decreasing the lead, increases crystallization and decreases the gloss. Crystals were obtained in the presence of 0.5 molecule of PbO .

7. These aventurine glazes did not seem restricted to any particular molecular or oxygen ratio, but came within the limits of good glazes.

III

Scope of Present Investigation.

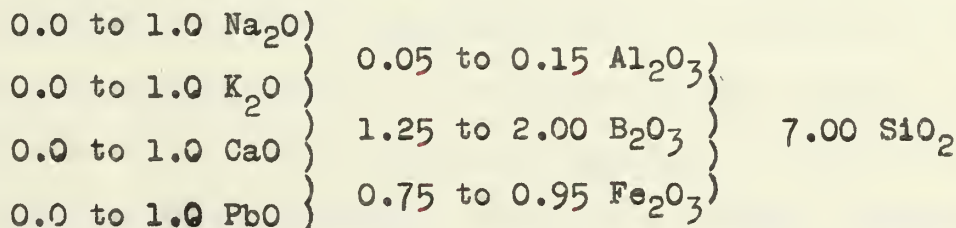
In the present investigation an attempt has been made to study the effect of variations in the alumina, ferric oxide, boric acid, and R O members in a cone 1 aventurine glaze. The correct heat treatment for the proper development of the aventurine effect was also studied as a means of control of the crystal growth.

IV

Method of Investigation

A good aventurine glaze maturing at cone 1 (1150°C) was selected as a basis of the study. The investigation was divided into two parts. In the first part the effect of variations in the alumina, boric acid, and ferric oxide content, and the effect of different heat treatments were studied. For the second part of the investigation, the best aventurine glaze developed in the first part was used as a basis for the investigation of variations in the RO constituents of the glaze.

The formula of the glaze under investigation with all the variables indicated is as follows:-



For the first part of the experiment only the R_2O_3 members were varied; the R O was kept constant at $1.0 \text{ Na}_2\text{O}$. The series was divided into three groups; the first group contained 0.05 moles of Alumina; the second group contained 0.10 moles of Alumina; and the third group contained 0.15 moles of Alumina. Each group was

divided into a rectangular field with four horizontal members representing variations in B_2O_3 content from 1.25 moles to 2.0 moles, and five vertical members representing variations in the Fe_2O_3 content from 0.75 moles to 0.95 moles.

V

Burning

All the trials were burned in glazed saggars in a down-draft coal-fired kiln, described in University of Illinois Bulletin, number 20, Vol. XI, #44. The first burn was conducted following the time temperature curve of Fig. 1 so that there was a considerable temperature difference throughout the kiln. Cone pads were placed in each sagger so that the heat treatment of each trial could be noted. The effect of temperature variations was in this manner closely studied. The next burn was conducted at cone 3 ($1190^{\circ}C$) and the final burn was conducted at cone 1 with uniform heat treatment throughout the kiln as far as possible.

In the second part of the work the variations were made in the R O members as already shown and the trials burned to cone 1. A representation of the field covered by four variables is difficult to place on paper but a visual representation of the field is of a pyramid with a triangular base. At the apex of the pyramid, 1.00 Na_2O is located with 1.00 K_2O , 1.00 CaO , and 1.00 PbO as the three corners of the base of the pyramid. To give a clearer conception of the field covered, I have drawn up a series of tri-axial diagrams representing horizontal planes parallel to the base of the pyramid which indicate clearly the variations in the R O members.

These glazes were burned to cone 1 in glazed saggars as before and the effect of the variable RO members was noted and tabulated.

VI

Method of Preparing Glazes

For the first burn of the first part of the investigation and for the second part, all the glaze materials were fritted as it takes a long time for the glaze to assimilate all the materials, and better aventurine glazes are produced if all chemical action has ceased before the final fusion of the glaze. For the second and third burns of the first part, 0.05 moles of alumina were omitted from the fritt and added as raw clay in an endeavor to take advantage of the plasticity of the raw clay to aid in keeping the fritt in suspension.

As most of the glaze is quite fluid before all of the more, refractory materials of the glaze are entirely dissolved, the method of drop-fritting the glaze was not employed. The materials were fritted in closed bottom crucibles to a quiet fusion and then poured into cold water for quenching.

After quenching, the fritts were ground in porcelain ball mills with water till they readily passed a 100 mesh screen. To keep the fritt in suspension in water, the best method devised was to saturate the suspension with aqueous ammonia while still in the ball mill. Using this method no difficulty was experienced in suspending the fritt in water.

In the first part of the investigation, the four corner fritts of groups I and III were prepared as described and all the intermediate glazes were prepared by molecular blending. This method of blending is described by Purdy and Fox in their work on fritted glazes.¹⁵ In the second part, the four corner fritts of the pyra-

¹⁵ R. C. Purdy and H. B. Fox "Fritted Glazes". Trans. Amer. Cer. Soc. Vol. IX, 1907 p. 95.

mid were prepared and the intermediate glazes were blended in the same manner as for the previous group.

VII

Materials Used

The following potter's materials were used for making the glazes and their formulae calculated as shown:

Clay - English china clay #3 - $\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 6\text{H}_2\text{O}$

Borax - $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$

Boric Acid - $\text{B}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$

White Lead - $\text{Pb}(\text{OH})_2 \cdot 2\text{PbCO}_3$

Whiting - CaCO_3

Soda Ash - Na_2CO_3

Potassium Carbonate - K_2CO_3

Ferric Oxide - Fe_2O_3

VIII

Trial Pieces

The trial pieces were rectangular biscuit tile $1\frac{1}{2}'' \times 3''$ manufactured by the U. S. Eucaustic Tile Company of Indianapolis, Indiana.

IX

First Part¹⁶

AVENTURINE GLAZE -Cone 1

The variations in the type formulae of all the glazes of the first part are as follows:-

$$1 \text{ Na}_2\text{O} \left\{ \begin{array}{l} 0.05 - 0.15 \text{ Al}_2\text{O}_3 \\ 1.25 - 2.00 \text{ B}_2\text{O}_3 \\ 0.75 - 0.95 \text{ Fe}_2\text{O}_3 \end{array} \right\} 7.00 \text{ SiO}_2$$

¹⁶ An experiment conducted by the Ceramics 5 class, University of Illinois, in the first semester of 1921-22. (Summary by J.S.Lathrop)

There are three groups of glazes prepared as follows:-

Group I ---- 0.05 Al_2O_3

Group II ---- 0.10 "

Group III---- 0.15 "

All groups used 1.00 Na_2O and 7.00 SiO_2 constant and varied as follows in B_2O_3 and Fe_2O_3 :-

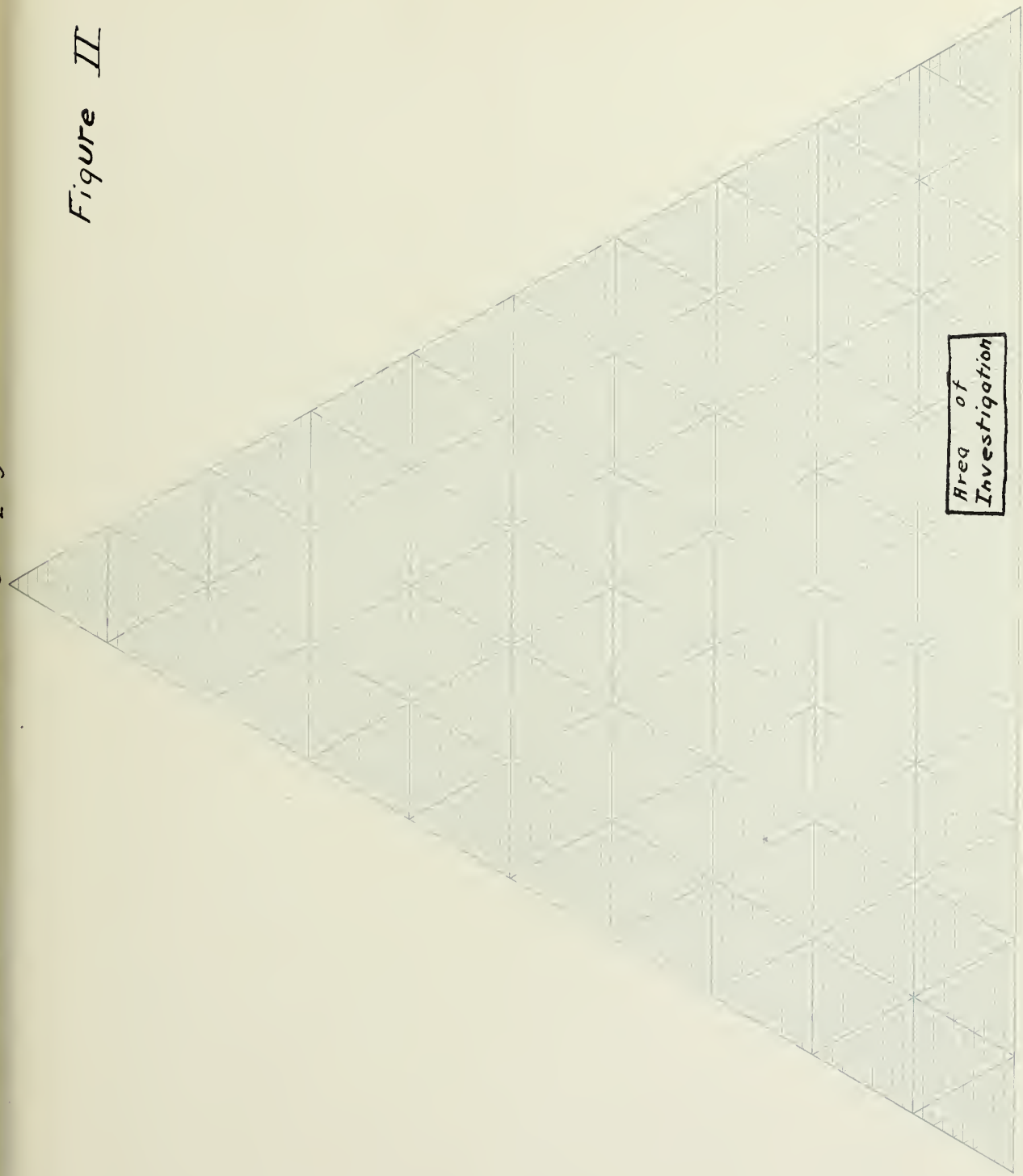
Fe_2O_3	A	B	C	D
0.95				
0.90				
0.85				
0.80				
0.75				
	1.25	1.50	1.75	2.00
	B_2O_3			

The figures at the left and bottom indicate the moles of oxide and the letters at the top with the figures at the bottom and the group number locate the glaze as IIC4, IIIB5, etc.

The tri-axial diagram, Fig. II, shows the small area of Aventurine Glazes figuring Al_2O_3 plus B_2O_3 plus SiO_2 as equal to 1. The diagram, Fig. III, which is an enlarged diagram of the portion of the tri-axial diagram of the area of the Aventurine Glazes gives the location of each glaze together with the results of the glost burn in diagrammatical form.

1.00 H_2O_3

Figure II



1.00 Fe_2O_3

1.00 B_2O_3

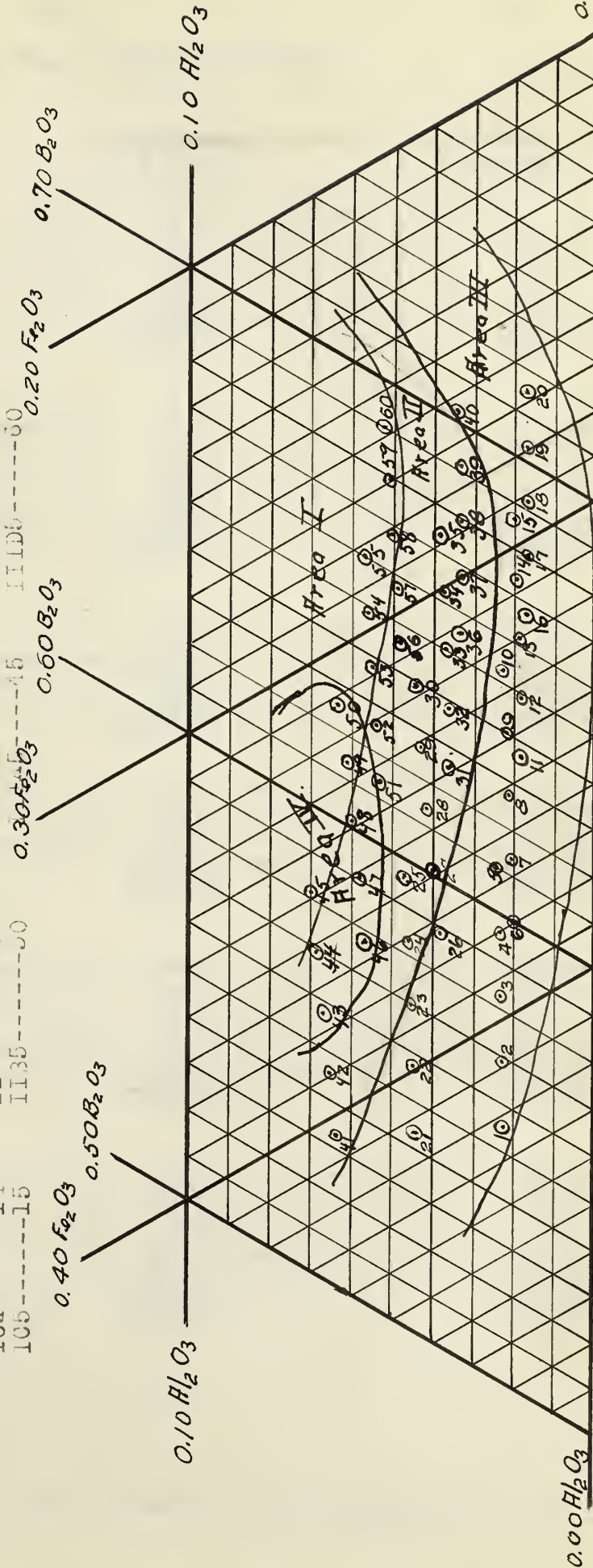
Figure III.

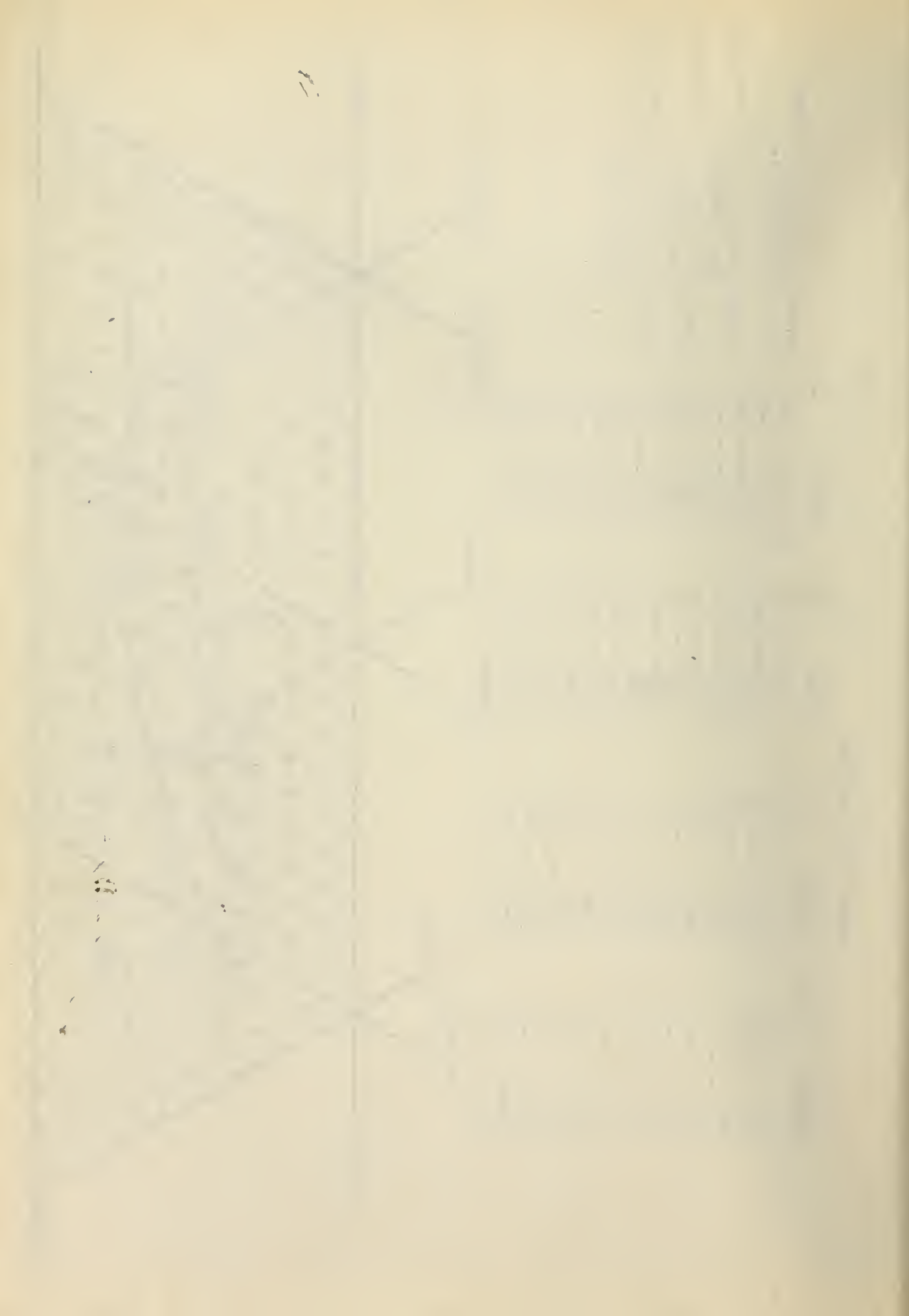
GLAZE and NUMBER

GLAZE	No.	GLAZE	No.
Ia1-----	1	IIc1-----	31
Ia2-----	2	IIc2-----	32
Ia3-----	3	IIc3-----	33
Ia4-----	4	IIc4-----	34
Ia5-----	5	IIc5-----	35
Ib1-----	6	IIc6-----	36
Ib2-----	7	IIc7-----	37
Ib3-----	8	IIc8-----	38
Ib4-----	9	IIc9-----	39
Ib5-----	10	IIc10-----	40
Ic1-----	11	IIc11-----	41
Ic2-----	12	IIc12-----	42
Ic3-----	13	IIc13-----	43
Ic4-----	14	IIc14-----	44
Ic5-----	15	IIc15-----	45

GLAZE	No.	GLAZE	No.
IIb1-----	46	IIc16-----	51
IIb2-----	47	IIc17-----	52
IIb3-----	48	IIc18-----	53
IIb4-----	49	IIc19-----	54
IIb5-----	50	IIc20-----	55
IIc1-----	51	IIc21-----	56
IIc2-----	52	IIc22-----	57
IIc3-----	53	IIc23-----	58
IIc4-----	54	IIc24-----	59
IIc5-----	55	IIc25-----	60
IIc6-----	56		
IIc7-----	57		
IIc8-----	58		
IIc9-----	59		
IIc10-----	60		

Area I:--area of lowest fusibility.
 Area I&II:--area of aventurine glazes of highest fusibility.
 Area III:--Area of highest fusibility.
 Area IV:--area of best aventurine glazes or true goldstones.





FRITT FORMULAE and COMBINING WEIGHTS

		Proportion Parts	Comb. Weight.
1A1	0.05 Clay-----	52.0	11.10
	0.625 Borax-----	954.0	126.00
	0.375 Soda Ash-----	159.0	23.25
	0.950 Fe ₂ O ₃ -----	608.0	152.00
	6.900 Flint-----	<u>1656.0</u>	<u>414.00</u>
		3429.0	726.35
1A6	0.05 Clay-----	52.0	11.10
	0.625 Borax-----	954.0	126.00
	0.375 Soda Ash-----	159.0	23.25
	0.750 Fe ₂ O ₃ -----	480.0	120.00
	6.900 Flint-----	<u>1656.0</u>	<u>414.00</u>
		3401.0	694.35
1D1	0.05 Clay-----	52.0	11.10
	1.000 Borax-----	1528.0	202.00
	0.950 Fe ₂ O ₃ -----	608.0	152.00
	6.900 Flint-----	<u>1656.0</u>	<u>414.00</u>
		3844.0	779.10
1D6	0.05 Clay-----	52.0	11.10
	1.000 Borax-----	1528.0	202.00
	0.750 Fe ₂ O ₃ -----	480.0	120.00
	6.900 Flint-----	<u>1656.0</u>	<u>414.00</u>
		3716.0	747.10
IIIA1	0.625 Borax-----	954.0	126.00
	0.375 Soda Ash-----	159.0	23.25
	0.150 Clay-----	155.0	33.30
	0.950 Fe ₂ O ₃ -----	608.0	152.00
	6.700 Flint-----	<u>1608.0</u>	<u>402.00</u>
		3483.0	736.55
IIIA6	0.625 Borax-----	954.0	126.00
	0.375 Soda Ash-----	159.0	23.25
	0.150 Clay-----	155.0	33.30
	0.750 Fe ₂ O ₃ -----	480.0	120.00
	6.700 Flint-----	<u>1608.0</u>	<u>402.00</u>
		3356.0	704.55

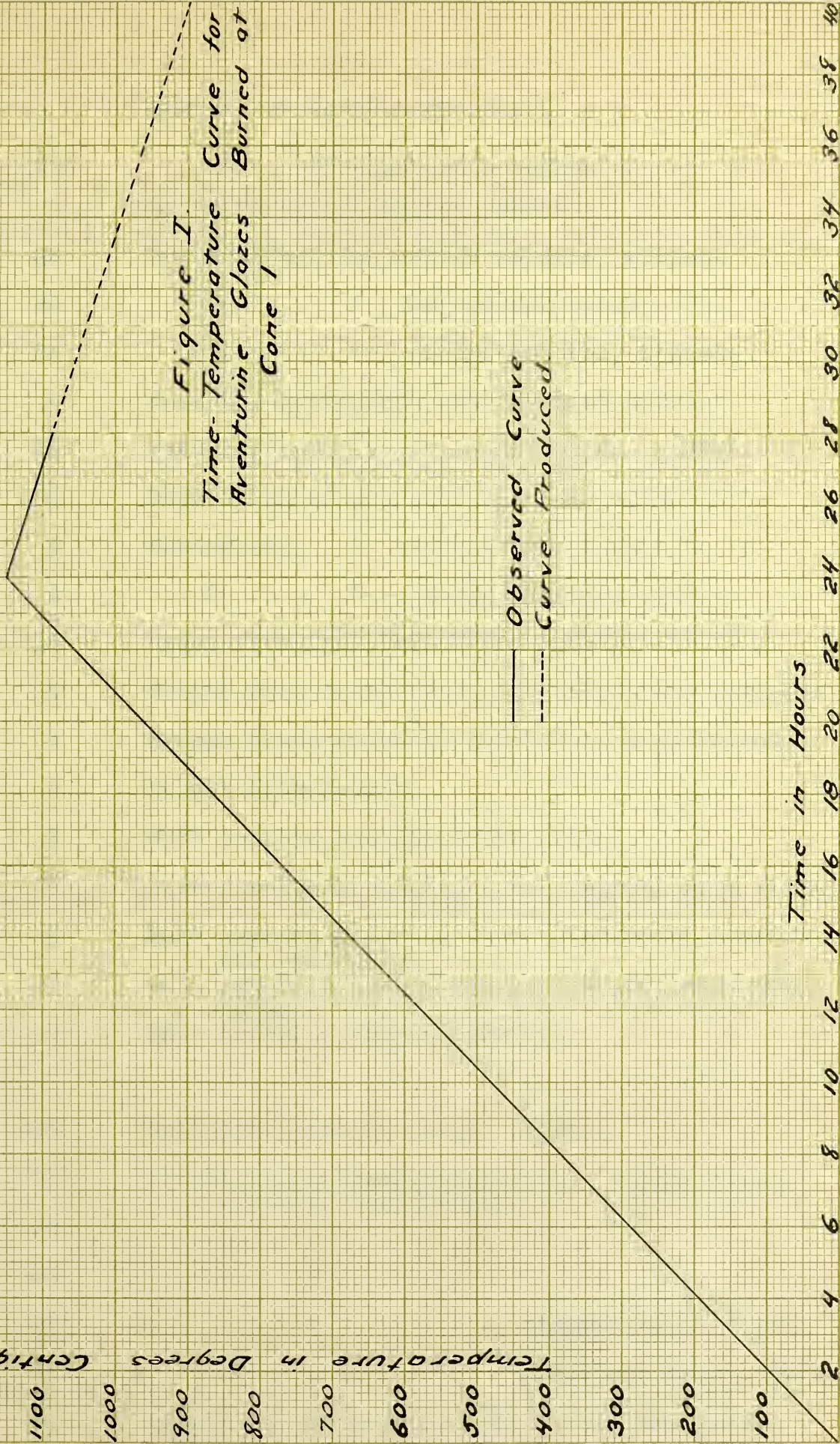
		Proportion Parts		Comb. Weight.
IIID1	1.00	Borax-----	1528.0	202.00
	0.15	Clay-----	155.0	33.30
	0.95	Fe ₂ O ₃ -----	608.0	152.00
	6.70	Flint-----	1608.0	402.00
			<u>3899.0</u>	<u>789.30</u>
IIID6	1.00	Borax-----	1528.0	202.00
	0.15	Clay-----	155.0	33.30
	0.75	Fe ₂ O ₃ -----	480.0	120.00
	6.70	Flint-----	1680.0	402.00
			<u>3771.0</u>	<u>757.30</u>

Temperature in Degrees Centigrade

Time in Hours

— Observed Curve
--- Curve Produced

Figure I.
Time-Temperature Curve for
Aventurine Glazes Burned at
Cone 1



RESULTS OF GLOST BURN Cone 1.

<u>Glaze</u>	<u>Cone</u>	<u>Description of glaze</u>
1	3	Over-fired,dull,copper colored.
2	08	Under-fired,dull,yellow colored, crazed.
3	08	" , " , yellow-red color, " .
4	08	" , " , copper colored, crazed.
5	3	Over-fired,bright,brownish-black color.
6	08	Under-fired,dull,yellow-red color, crazed.
7	3	Over-fired,bright,mottled brown color.
8	3	Over-fired, " ,dark maroon color.
9	3	" , " , Brownish-black color.
10	08	Under-fired,dull,brick-red color.
11	3	Bright,deep brown color,few aventurine spangles.
12	3	Bright,black,speckled aventurine separations.
13	3	Bright,brown-black.
14	3	Matt texture,reddish-brown color.
15	3	Over-fired,dull,copper color dappled with black.
16	3	Matt texture,coppercolor,bubbled,heavy aventurine separation.
17	3	Matt eggshell texture,dappled brown and copper color.
18	3	Matt texture, copper colored.
19	3	" , " " .
20	08	Dull,dirty yellow color, crazed.
21	05	Bright,transparent,yellow,white bubbly separations on the surface.
22	06	"
23	06	"
24	06	" deeper yellow color.
25	03	" yellowish brown color.
26	5	Bright,yellowish brown color,bubbled,crazed.

<u>Glaze</u>	<u>Cone</u>	<u>Description of Glaze</u>
27	5	Bright, brownish-black color, mottled effect.
28	05	Bright, yellow color.
29	05	Bright, brownish yellow color.
30	03	" , yellowish brown color, pinholed.
31	02	Bright, dark brown with aventurine separations, pinholed.
32	02	Bright, mahogany color, little aventurine, crazed.
33	05	" , dark yellow color, crazed.
34	05	" , " , " , bubbled.
35	01	" , " , " , pinholed.
36	2	Bright, deep purple color, checkered in glaze effect, very fine aventurine, pinholed, cracked.
37	02	Bright, black color with heavy separations of copper colored aggregates.
38	02	The same with less metallic separations.
39	4	Bright, reddish-black color with white, bubbly separations.
40	01	Bright, yellow color, bubbled.
41	05	Bright, yellow color, red aventurine only on thin edges, crazed.
42	05	"
43	05	Bright, reddish-brown color, filled with very minute aventurine separations, crazed.
44	01	The same with larger aventurine separations.
45	2	Bright, brown color, heavy with aventurine separations, beautiful red and gold aventurine spangles around the edges.
46	05	The same except that the color is darker.
47	05	The same.
48	05	Bright, orange color, very heavy and minute aventurine separations, crazed.
49	2	Bright, dark purple color with one patch of beautiful red and gold aventurine spangles.
50	01	Dull, the greater part of the piece red and full of true goldstone spangles.
51	05	True matt texture, purplish-pink color, evidently a micro-crystalline structure.

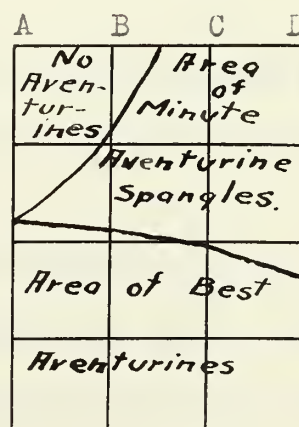
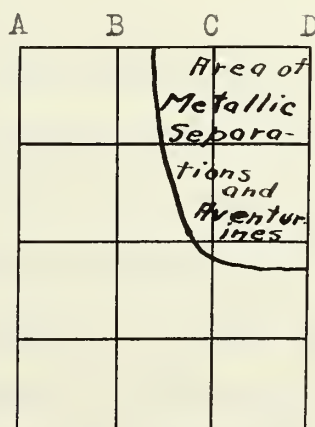
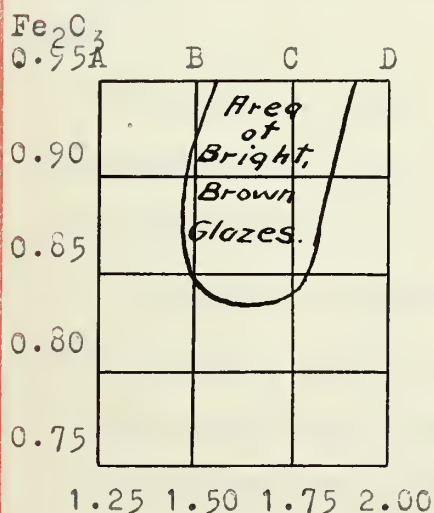
<u>Glaze</u>	<u>Cone</u>	<u>Description of Glaze</u>
52	06	The same but with more of the appearance of aventurine spangles in the glaze.
53	04	The same but lighter in color.
54	01	Bright, yellowish-brown color with heavy aventurine spangles around the edge and few inside, crazed.
55	01	Bright, yellow color, aventurine on edges, crazed.
56	05	Bright, deep brownish-purple color with very minute and finely divided aventurine spangles, not crazed and a very attractive glaze.
57	05	Matt texture but in other respects the same as glaze 56 and a much lighter shade.
58	05	The same except a brighter finish and darker color.
59	01	Bright, yellow color, heavy aventurine on the edges and very few spangles inside, crazed.
60	04	Bright, light yellow color and very few aventurine spangles, crazed.

The diagram below show the three groups of glazes with the different areas marked off on them.

Group I
0.05 Al_2O_3

Group II
0.10 Al_2O_3

Group III
0.15 Al_2O_3



B_2O_3

Discussion of Results

These results indicate that with this glaze composition, an alumina content of 0.15 equivalents produces better conditions for the development of aventurine glazes than does a lower alumina content. The results also indicate that the higher alumina content produces more easily fusible glazes than do the lower alumina contents. This may seem contradictory to ordinary experience but the results point to this conclusion.

The glazes with 0.05 equivalents of alumina showed no aventurine tendencies at all. This may be due to the heat treatment which they received; all of these glazes were burned either too high or too low. However, some of the other glazes with a higher alumina content which were burned either excessively high or excessively low showed brighter glazes and contained aventurine spangles. One glaze alone in this group showed tendencies towards the development of aventurine effects and that was the one highest in boric acid and highest in iron oxide. This glaze only showed the spangles under the electric light and was dull and unsatisfactory.

The area of high iron oxide and medium boric acid content with low alumina gave bright brown or black colored glazes which lost their gloss on contact with the air.

The group of glazes containing 0.10 equivalents of alumina developed all bright glazes. In this group only the glazes highest in iron oxide and highest in boric acid showed any separation of the iron from the glaze. In some of these glazes, the separation was thin, minutely divided aventurine spangles but in one glaze, number 37, it separated as large metallic separations which gave a

rather attractive glaze but not of the aventurine effect. The color range does not seem to be uniform except that the glazes high in iron oxide and low in boric acid and those low in iron oxide and high in boric acid were lighter colored than the others. The other colors were dark yellow, brown, black and purple.

The group containing 0.15 equivalents of alumina showed the greatest tendency to produce aventurines. All of these glazes except the ones high in iron oxide and low in boric acid and those high in boric acid and low in iron oxide showed more or less aventurine spangles. These exceptions produced yellow colored glazes while the others produced darker colors. The glazes lowest in iron oxide and lowest in boric acid showed the best aventurines, producing large patches of the true red and gold goldstone effects. In this group the glazes highest in iron oxide and highest in boric acid had a tendency to produce matt textures.

In all the groups the glazes highest in iron oxide and lowest in boric acid and those highest in boric acid and lowest in iron showed more of a tendency to craze than the others.

One peculiar effect noticed is that in each group, the glaze with the highest iron oxide and highest boric acid content produced a bright brownish-purple colored glaze which had a good, glossy finish and good texture. This color grew darker as the alumina content increased. The glaze of this composition in the 0.15 alumina group was the best colored and finished, being glossy and smooth with no pinholing or crazing. It was uniform in color and texture and was thick with very tiny, minute aventurine spangles which did not show up well except under the electric light. The glaze developed well clear down to the edges of the piece. It dev-

eloped at cone 05 and makes a very pleasing glaze.

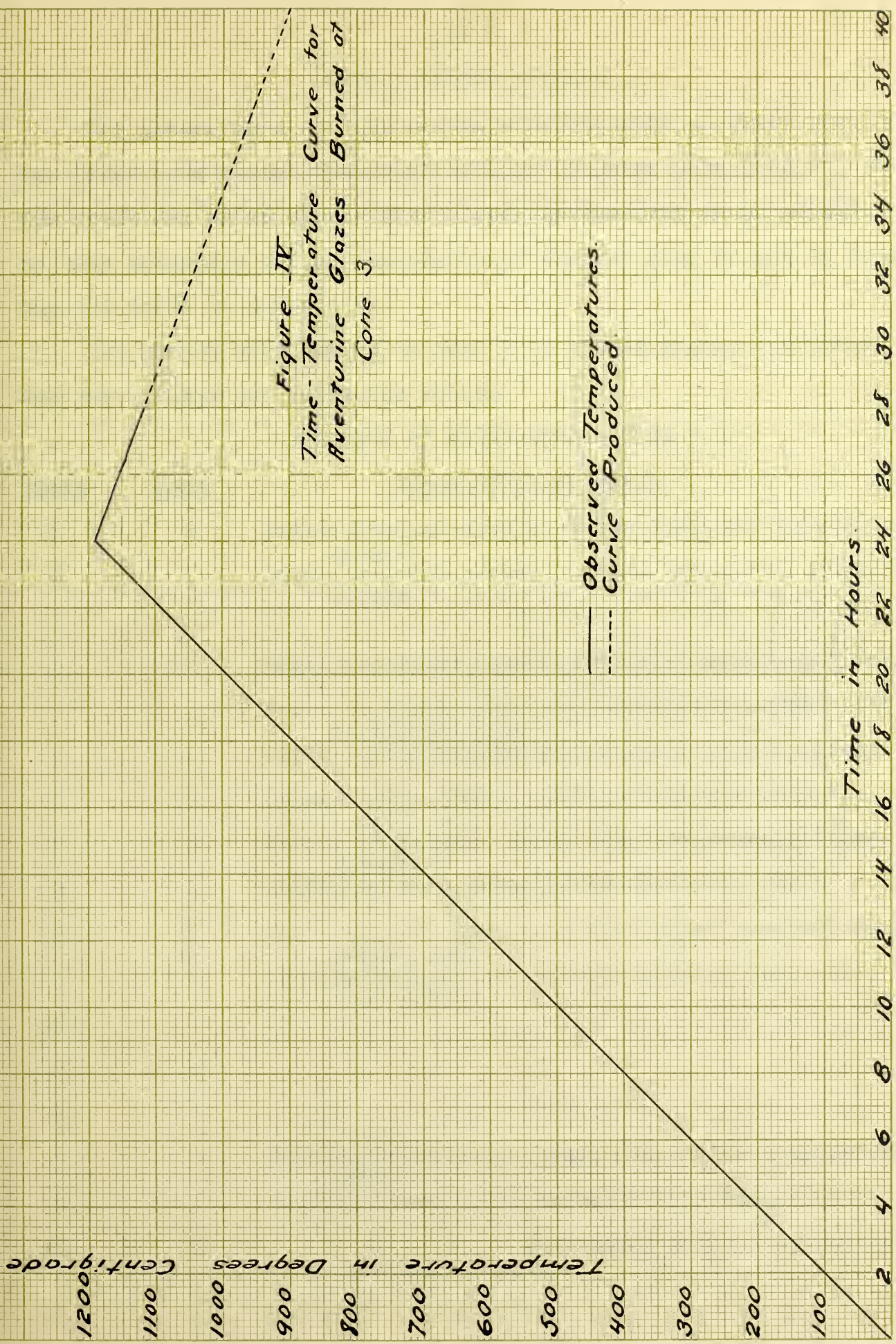
The heat distribution through the kiln was not uniform so the heat treatment of the glazes varies and it is hard to draw conclusions as a result.

Some of the glazes were dipped too thick and others too thin. Most of the glazes showed improper blending of materials.

With these handicaps it is hard to draw any uniform conclusions from the results. The heat treatment given the kiln seems to have been poor and the cooling especially seems to have been too rapid for proper development of aventurine glazes.

Conclusions.

1. 0.15 equivalents of alumina gives a better condition for the development of aventurines than a lower content.
2. A low iron oxide together with a low boric acid content in this glaze with highest alumina content produces the best goldstone effects.
3. High iron oxide content with high boric acid in the high alumina glaze tends to give matt textures.
4. High iron oxide with low boric acid and high boric acid with low iron gives yellow glazes with crazing tendencies.
5. Increasing alumina content gives more easily fusible glazes.
6. The best temperature to develop these aventurines is cone 1 or cone 2.
7. A good bright, brownish purple glaze maturing at cone 05 is developed with 0.15 alumina, 0.95 iron oxide and 2.00 boric acid in this base glaze.
8. The glaze blending and heat treatment must be accurate and carefully handled to produce aventurine glazes.



Cone 3 (1190° C) Burn

The glazes used in this series were the same as those used for the first burn except that 0.05 moles of Alumina were left out of the fritt and added to the glaze later as raw clay in an attempt to take advantage of the plasticity of the raw clay to aid in holding the fritt in suspension.

The glazes were burned to cone 3 in glazed saggars as before and the results are tabulated below.

RESULTS OF GLOST BURN - Cone 3.

<u>Glaze</u>	<u>Cone</u>	<u>Description of glaze</u>
1	2	Light brownish purple, large metallic separations, glossy.
2	1	Light brownish purple, minute aventurin crystals, glossy.
3	1	"
4	2	Light red color, good aventurine separation, dull.
5	3	Brown to black color, red aventurine separations on edges, dull.
6	1	Purple color, minute aventurine crystals, glossy.
7	3	Golden color, heavy metallic separations, dull.
8	2	Purple to golden, heavy aventurine separations, glossy.
9	3	Golden, heavy aventurine separations, dull.
10	3	Dirty golden color, good aventurine separations on edges, dull.
11	4	Reddish gold color, entirely crystallized, dull, overburned.
12	4	"
13	4	"
14	4	"
15	3	Reddish-brown color, heavy aventurine separations, dull.
16	3	Reddish-brown color, metallic separations, dull.
17	3	" , beautiful aventurine crystals on edges, bright

<u>Glaze</u>	<u>Cone</u>	<u>Description of glaze</u>
18	4	Reddish golden color, entirely crystallized, dull, over-burned.
19	4	"
20	4	Red to black color, heavy aventurine separations, dull.
21	03	Light brownish purple color, no crystals, bright.
22	03	"
23	03	"
24	03	"
25	01	Black, few metallic separations, glossy.
26	3	Yellow, entirely crystallized, dull, overburned.
27	4	Muddy gray color, entirely crystallized, dull, over-burned.
28	4	"
29	1	Reddish gold color, beautiful crystals, dull.
30	3	Mottled gold and black, metallic separation, dull.
31	3	Reddish color, entirely crystallized, dull, over-burned.
32	02	Muddy purple color, metallic separations, dull, under-fired.
33	01	Purple to golden, heavy aventurine separations, glossy.
34	1	"
35	2	Mottled red and gold, heavy metallic separation, dull.
36	3	Dirty golden color, entirely crystallized, dull, overburned.
37	02	Dark purple, golden aventurine crystals, glossy.
38	3	Red to golden color, entirely crystallized, dull, overburned.
39	3	"
40	2	Red to black metallic and aventurine separations, glossy.
41	03	Dull reddish brown color, no crystals, semi-glossy.
42	02	Brownish purple, minute aventurine crystals, semi-glossy.
43	1	Golden brown color, heavy minute crystals, glossy.
44	1	Brownish purple color, few minute crystals, glossy.

<u>Glaze</u>	<u>Cone</u>	<u>Description of glaze</u>
45	1	Golden red color, beautiful aventurine crystals, glossy.
46	2	Dark gray color, aventurine separations, dull, overburned.
47	02	Purple color, no crystals, glossy, under-fired.
48	02	Purple gray, shows tendency to crystallize, glossy.
49	02	Purple, no crystals, glossy.
50	1	Reddish purple, good aventurine crystals, glossy.
51	3	Golden black color, metallic separations, dull, overburned.
52	01	Grayish purple, few aventurine crystals, glossy.
53	01	Purple color, few aventurine separations, glossy.
54	1	Purple to golden red, heavy aventurine separations, glossy.
55	1	Purple to dark red, beautiful aventurine separations, glossy.
56	2	Dull black, few aventurine separations, semi-glossy.
57	2	Dull black to golden, heavy aventurine separations, glossy.
58	1	Purple to golden, heavy aventurine separations, glossy.
59	1	Purple to red-golden, heavy aventurine separations, glossy.
60	2	Red, mottled metallic separations, dull.

Discussion of Results of Cone 3 Burn.

The conclusions drawn from the first burn are pretty well demonstrated by this burn to be correct. Evidently cone 3 is too high a temperature for these glazes, as most of them are overburned. One point is brought out quite strongly by this burn and that is the effect of alumina on the development of aventurine crystals. The glazes in Group I with only 0.05 moles of alumina are nearly all of them entirely crystallized, indicating that the glaze was quite fluid at cone 3, thus allowing heavy crystal separations. The glaze in Group III, on the other hand, have not crystallized so

heavily, indicating that the glazes in this group were more viscous at cone 3 and did not permit of such heavy crystallization. The glazes of Group II are intermediate in this respect.

The tendency of the Al_2O_3 seems to be to give a deeper and richer color to the glaze as the quantity increases as well as to decrease the fluidity of the glaze.

The glazes with lowest iron and lowest boric acid content seem to give the best aventurine crystals.

Conclusions from Cone 3 Burn.

1. Cone 3 is too high a temperature for these glazes, and is likely the proper temperature at which to mature these aventurine glazes.
2. Low boric acid and low iron give the best aventurine crystals.
3. The other conclusions of the first burn are verified

Third Burn of First Part - Cone 1.

This series was the same as the second series but was burned at cone 1 with careful heat regulation and with a little longer time allowed for the maximum temperature.

Results of Burn at Cone 1 (1150°C)

<u>Glaze</u>	<u>Cone</u>	<u>Description of glaze</u>
1	01	Purple color, no crystals, glossy, crazed.
2	01	" , few minute crystals, glossy, crazed.
3	02	" , " , dull, crazed.
4	1	Golden red, almost entirely crystallized, dull.
5	1	Reddish black, beautiful aventurine crystals, glossy.
6	1	Brownish purple, heavy with minute golden crystals, glossy.
7	1	"
8	2	Golden, entirely crystallized, dull.
9	2	" , " , " .
10	2	Red-golden, entirely crystallized, dull.
11	2	" , " , " .
12	2	" , " , " .
13	2	Golden, entirely crystallized, dull.
14	2	" , " , " .
15	2	Brownish-red, entirely crystallized, dull.
16	01	Brownish-black, few metallic separations, glossy.
17	01	Brown, few metallic separations, glossy.
18	1	Brown-red, patches of good aventurine crystals, glossy.
19	2	Brown-red, entirely crystallized, dull.
20	1	Purple-black to golden, heavy with minute crystals, glossy.
21	03	Red, no crystals, not developed, dull.
22	03	" , " , " .
23		
24	1	Light golden, almost entirely crystallized, dull.
25	1	Gunmetal color, patches of good crystals, glossy.
26	1	Red-purple, no crystals, glossy.

<u>Glaze</u>	<u>Cone</u>	<u>Description of glaze</u>
27	1	Red-purple, no crystals, glossy.
28	1	Gray-purple, minute aventurine crystals, glossy.
29	2	Red-golden, entirely crystallized, glossy.
30	1	Black, beautifully crystallized, glossy.
31	1	Red-purple, no crystals, glossy, crazed.
32	1	" , " , " , " .
33	1	Red-purple, few minute crystals, glossy, crazed.
34	1	Red-purple to golden aventurine, glossy.
35	1	Black, metallic separations, glossy.
36	1	Red-purple, no crystals, crazed, glossy.
37	1	Dark purple, no crystals, crazed, glossy.
38	1	Gray-purple, minute crystals, glossy.
39	2	Golden, entirely crystallized, dull.
40	1	Black, beautifully crystallized, glossy.
41	03	Dull brown, no crystals, dull, underfired.
42	1	Brown-purple, no crystals, glossy, crazed.
43	1	Purple, minute crystals, glossy.
44	1	Gold-purple, many minute crystals, glossy.
45	1	Red beautiful aventurine crystals, glossy.
46	1	Purple, no crystals, crazed, glossy.
47	1	" , " , " , " .
48	1	" , " , " , " .
49	1	" , " , " , " .
50	1	Red-brown, heavily crystallized, matt texture.
51	1	Red, no crystals, glossy, crazed.
52	1	Mottled purple, no crystals, glossy.
53	1	Red-purple, no crystals, glossy, crazed.

<u>Glaze</u>	<u>Cone</u>	<u>Description of glaze</u>
54	1	Red-purple, no crystals, glossy, crazed.
55	1	" ,few minute crystals , glossy, crazed.
56	1	Red, no crystals, glossy, crazed.
57	1	" , " , " , " .
58	1	Purple-red,no crystals, glossy, crazed.
59	1	Red-purple, " , " , " .
60	1	Purple, no crystals, glossy, crazed.

Discussion of Results of Third Burn (at Cone 1.)

As in the previous burns, the higher alumina content gives a more viscous glaze and retards crystallization to a very marked degree. The temperature of this burn is evidently the proper maturing temperature for these glazes as most of them turned out glossy and smooth.

The low iron and low boric acid glazes give the best aventurine crystals, and the most beautiful glazes. Increased iron content seems to give the glaze more of a red color than the lower iron content.

When these glazes do not develop any aventurine effect they nevertheless produce beautiful mottled purple colored glazes.

Conclusions from Third Burn (at cone 1)

The conclusions drawn from this burn coincide with the conclusions of the two previous burns.

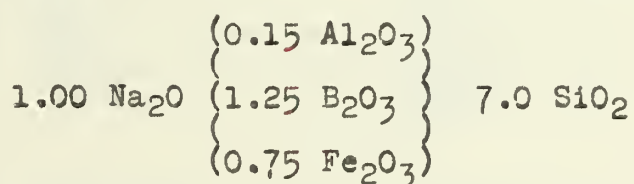
General Conclusions on Effect of Heat Treatment and Variations in the content of Alumina, iron and boric acid.

The general conclusions drawn from the foregoing work are:

1. Aventurine glazes with these variable compositions mature

at cone 1.

2. Increasing alumina content retards crystallization.
3. Best aventurine glazes were obtained with low iron and low borid acid content.
4. Least crazing was found in areas of maximum crystallization.
5. In areas where no crystallization takes place, beautiful mottled, glossy glazes are produced with a red-purple color.
6. To produce the best results, the glaze materials must be entirely fritted together before being applied to the piece.
7. Careful blending and careful firing and cooling must be regarded for the proper development of aventurine glazes.
8. The best aventurine glaze produced has the following composition:



X

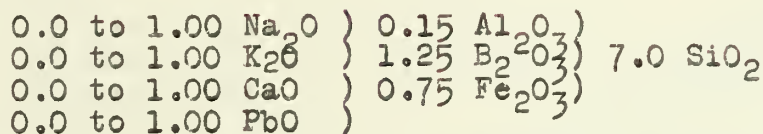
Part II.

In the second part of the investigation an attempt was made to determine the effects of variations in the R O group on the development of aventurine glazes and their maturing temperature. This was accomplished as outlined in the Method of Investigation. The tri-axial diagrams showing the R O composition of each glaze are given in diagrams V,VI,VII,VIII, and IX.

The method of preparing the glazes and of blending is the same as given for Part I, Series I and the firing was carried out to

cone 1.

The glaze formula with the R O variations used in this work is as follows:-



The glaze compositions, batch weights, and RO components of each glaze are given in the following tables.

Glaze composition and Batch Weights.

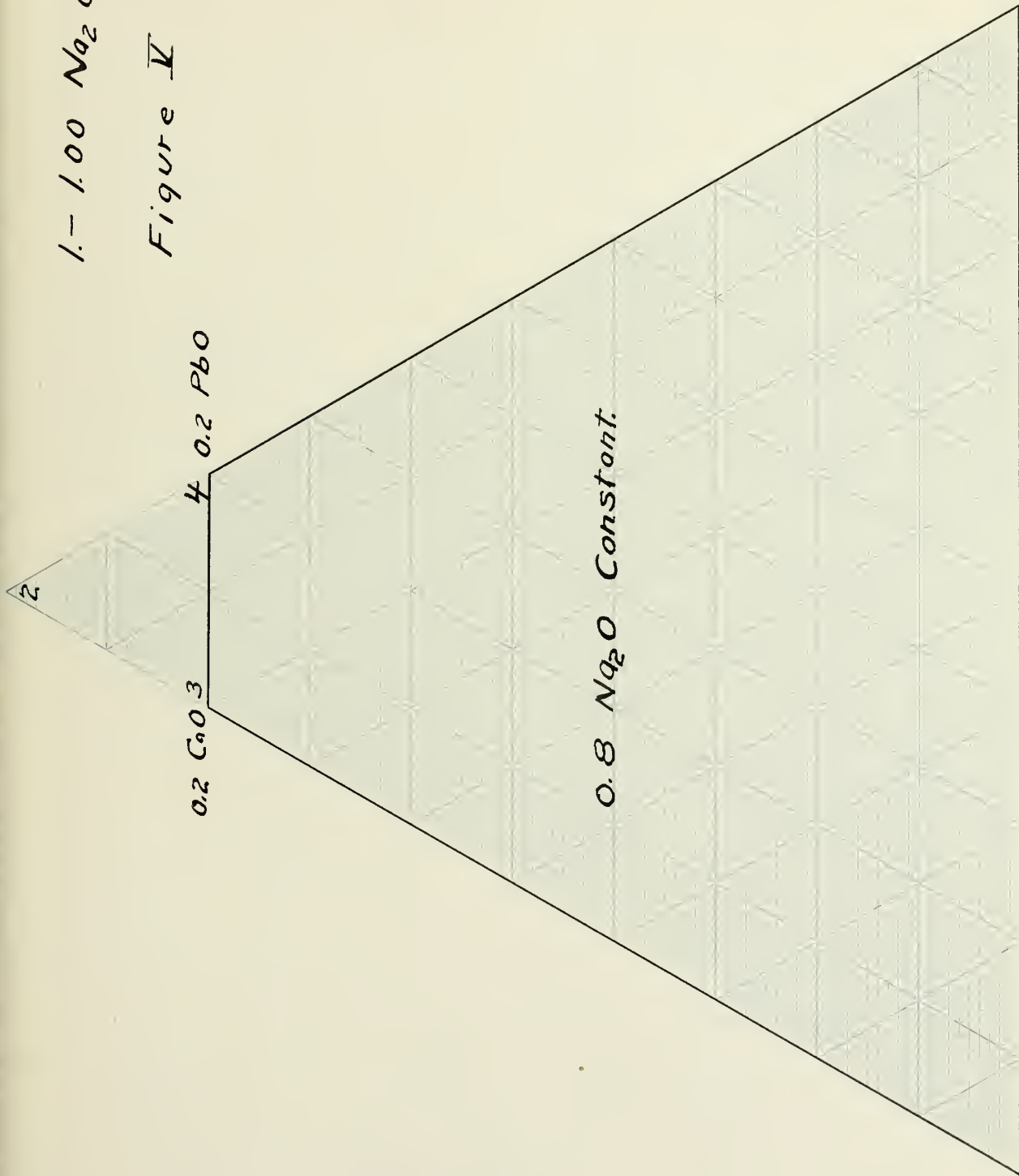
				Comb.
				Weight.
Glaze 1:				
0.625	Borax-----	1908.0	-----	126.00
0.375	Soda Ash-----	318.4	-----	23.25
0.15	Clay-----	309.6	-----	34.20
0.70	Flint-----	3216.0	-----	402.00
0.75	Fe ₂ O ₃ -----	960.0	-----	120.00
		6712.0		705.45
Glaze 36:				
1.00	K ₂ CO ₃ -----	1104.0	-----	94.00
0.15	Clay-----	309.6	-----	34.20
6.70	Flint-----	3216.0	-----	402.00
1.25	B ₂ O ₃ -----	700.0	-----	87.50
0.75	Fe ₂ O ₃ -----	960.0	-----	120.00
		6289.6		737.70
Glaze 51:				
1.00	Whiting-----	800.0	-----	56.00
0.15	Clay-----	309.6	-----	34.20
6.70	Flint-----	3216.0	-----	402.00
1.25	B ₂ O ₃ -----	700.0	-----	87.50
0.75	Fe ₂ O ₃ -----	960.0	-----	120.00
		5985.6		699.70
Glaze 56:				
1.00	White lead-----	1035.0	-----	223.00
0.15	Clay-----	309.6	-----	34.20
6.70	Flint-----	3216.0	-----	402.00
1.25	B ₂ O ₃ -----	700.0	-----	87.50
0.75	Fe ₂ O ₃ -----	960.0	-----	120.00
		6969.6		866.70

1.- 1.00 Na_2O

Figure V

0.2 CaO 3 4 0.2 PbO

0.8 Na_2O Constant.



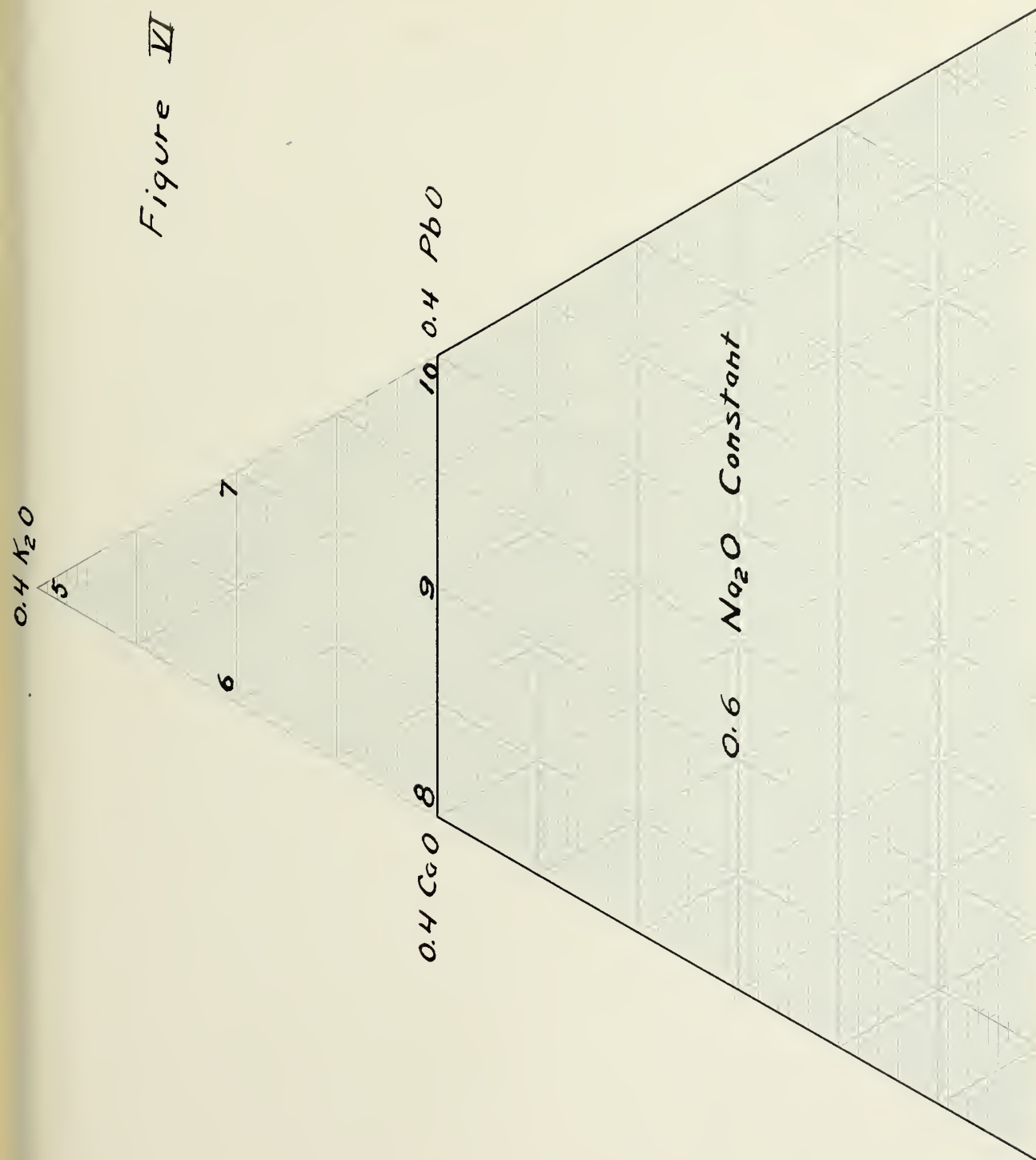
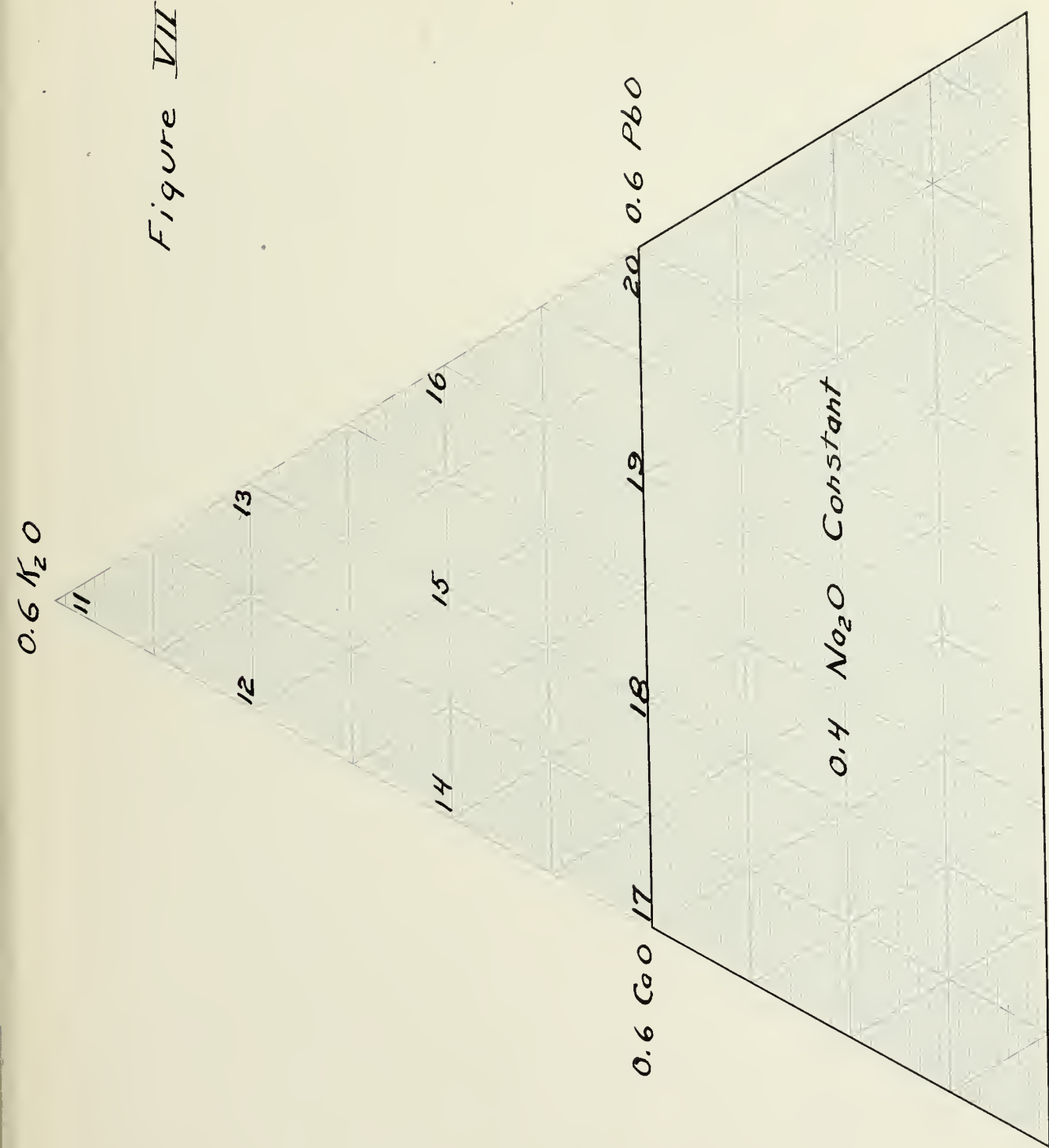


Figure VI

Figure VII



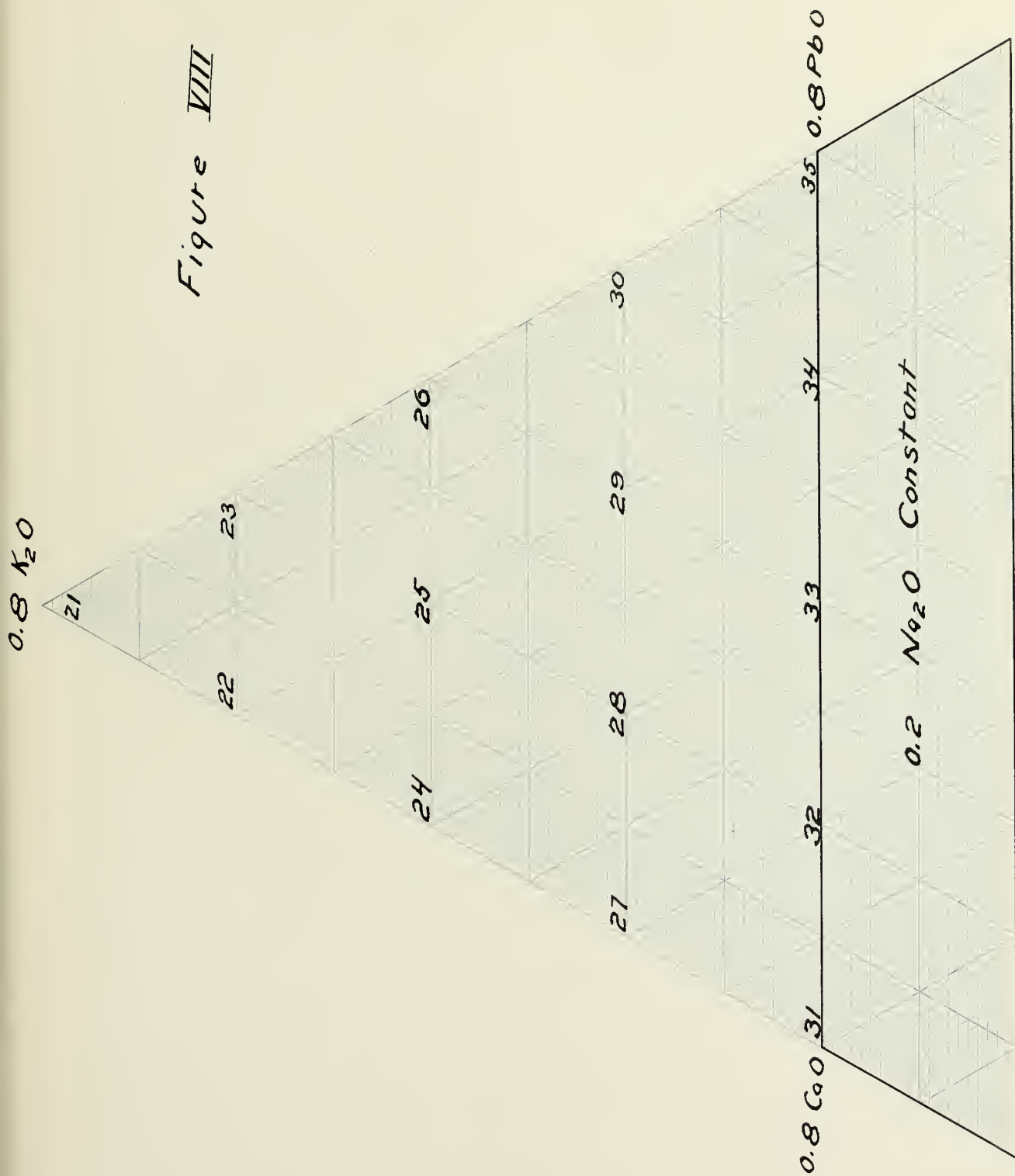
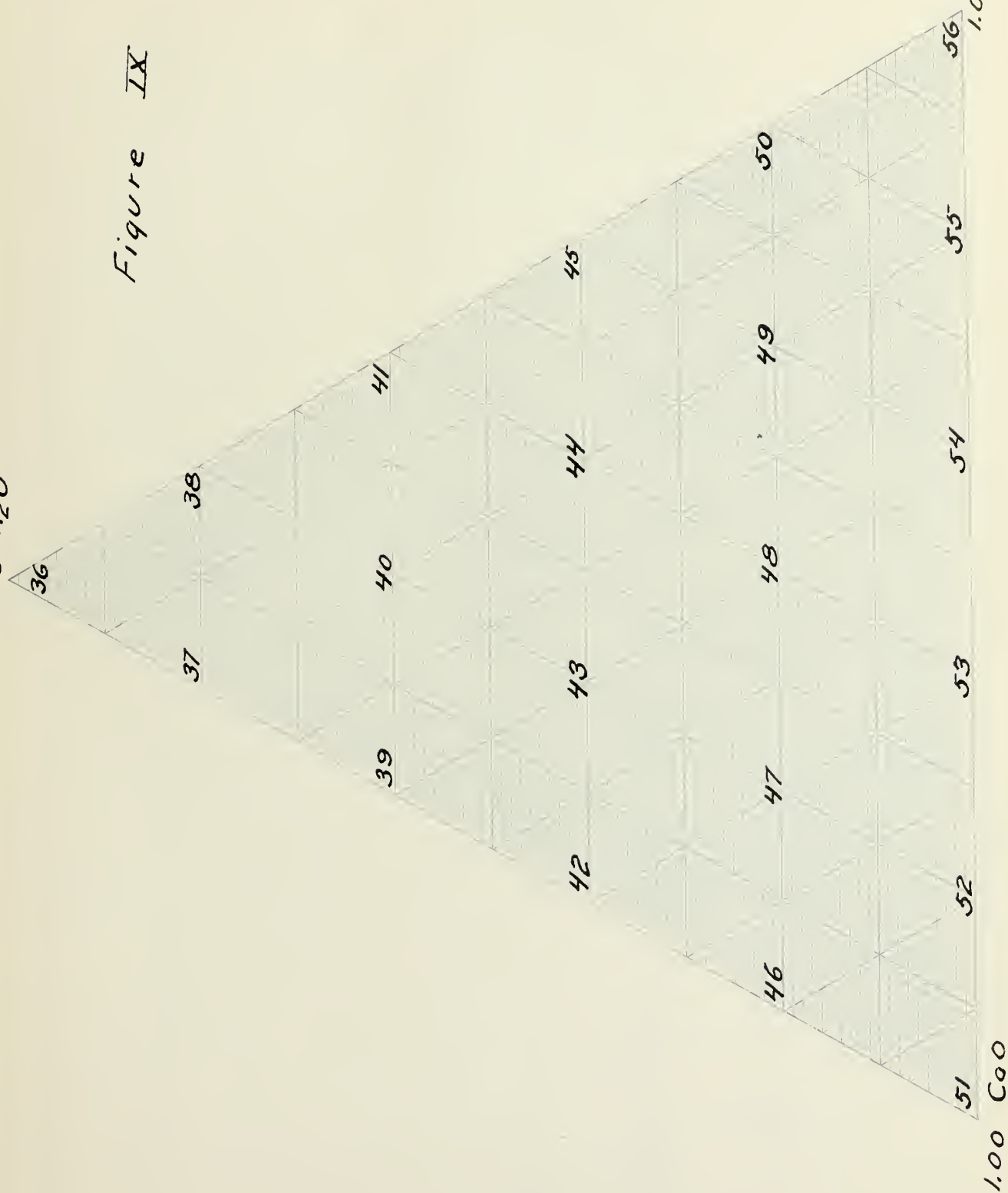


Figure IX

1.00 K_2O



RO Components of Part II

<u>Glaze</u>	<u>RO Components.</u>	
1	1.00	Na2O
2	0.8	Na2O, 0.2 K2O
3	0.8	Na2O, 0.2 CaO
4	0.8	Na2O, 0.2 PbO
5	0.6	Na2O, 0.4 K2O
6	0.6	Na2O, 0.2 K2O, 0.2 CaO
7	0.6	Na2O, 0.2 K2O, 0.2 PbO
8	0.6	Na2O, 0.4 CaO
9	0.6	Na2O, 0.2 CaO, 0.2 PbO
10	0.6	Na2O, 0.4 PbO
11	0.4	Na2O, 0.6 K2O
12	0.4	Na2O, 0.4 K2O, 0.2 CaO
13	0.4	Na2O, 0.4 K2O, 0.2 PbO
14	0.4	Na2O, 0.2 K2O, 0.4 CaO
15	0.4	Na2O, 0.2 K2O, 0.2 CaO, 0.2 PbO
16	0.4	Na2O, 0.2 K2O, 0.4 PbO
17	0.4	Na2O, 0.6 CaO
18	0.4	Na2O, 0.4 CaO, 0.2 PbO
19	0.4	Na2O, 0.2 CaO, 0.4 PbO
20	0.4	Na2O, 0.6 PbO
21	0.2	Na2O, 0.8 K2O
22	0.2	Na2O, 0.6 K2O, 0.2 CaO
23	0.2	Na2O, 0.6 K2O, 0.2 PbO
24	0.2	Na2O, 0.4 K2O, 0.4 CaO
25	0.2	Na2O, 0.4 K2O, 0.2 CaO, 0.2 PbO
26	0.2	Na2O, 0.4 K2O, 0.4 PbO
27	0.2	Na2O, 0.2 K2O, 0.6 CaO
28	0.2	Na2O, 0.2 K2O, 0.4 CaO, 0.2 PbO
29	0.2	Na2O, 0.2 K2O, 0.2 CaO, 0.4 PbO
30	0.2	Na2O, 0.2 K2O, 0.6 PbO
31	0.2	Na2O, 0.8 CaO
32	0.2	Na2O, 0.6 CaO, 0.2 PbO
33	0.2	Na2O, 0.4 CaO, 0.4 PbO
34	0.2	Na2O, 0.2 CaO, 0.6 PbO
35	0.2	Na2O, 0.8 PbO
36	1.0	K2O
37	0.8	K2O, 0.2 CaO
38	0.8	K2O, 0.2 PbO
39	0.6	K2O, 0.4 CaO
40	0.6	K2O, 0.2 CaO, 0.2 PbO
41	0.6	K2O, 0.4 PbO
42	0.4	K2O, 0.6 CaO
43	0.4	K2O, 0.4 CaO, 0.2 PbO
44	0.4	K2O, 0.2 CaO, 0.4 PbO
45	0.4	K2O, 0.6 PbO
46	0.2	K2O, 0.8 CaO
47	0.2	K2O, 0.6 CaO, 0.2 PbO
48	0.2	K2O, 0.4 CaO, 0.4 PbO
49	0.2	K2O, 0.2 CaO, 0.6 PbO
50	0.2	K2O, 0.8 PbO

<u>Glaze</u>	<u>RO Components</u>
51 -----	1.0 CaO
52 -----	0.8 CaO, 0.2 PbO
53 -----	0.6 CaO, 0.4 PbO
54 -----	0.4 CaO, 0.6 PbO
55 -----	0.2 CaO, 0.8 PbO
56 -----	1.0 PbO

RESULTS OF GLOST BURN--VARIATIONS IN RO MEMBERS - Cone 1.

<u>Glaze</u>	<u>Cone</u>	<u>Description of glaze</u>
1	1	Purple red with good aventurine crystals, glossy.
2	1	Black, good aventurine crystals, glossy.
3	1	Deep brown, good crystallization, matt texture.
4	1	Purple-brown, no crystals, glossy.
5	1	Reddish-black, good crystallization, matt texture.
6	1	Black, metallic separations, glossy.
7	1	Red-purple, no crystals, glossy.
8	1	Purple, no crystals, semi-matt texture.
9	1	Brown-purple, no crystals, glossy.
10	1	"
11	2	Black, metallic and aventurine separations, glossy.
12	1	Red-brown, minute aventurine crystals, glossy.
13	1	Brown-purple, no crystals, glossy.
14	1	Purple, no crystals, glossy.
15	1	Red, no crystals, glossy.
16	1	Red, no crystals, glossy.
17	1	Red-purple, no crystals, glossy.
18	1	"
19	1	Red-purple, few minute crystals, glossy.
20	1	Red, no crystals, glossy.
21	1	Red-gold, good aventurine, semi-matt.

<u>Glaze</u>	<u>Cone</u>	<u>Description of glaze</u>
22	1	Deep purple, good aventurine, glossy.
23	1	Red-purple, no crystals, glossy.
24	1	Deep brown-purple, few crystals, glossy.
25	1	Deep gray-purple, few crystals, glossy.
26	1	Red-purple, no crystals, glossy.
27	1	Deep gray-purple, very minute crystals, glossy.
28	1	" , no crystals, glossy.
29	1	" , " , " .
30	1	Red-purple, no crystals, glossy.
31	1	Dull black, very few crystals, dull.
32	1	Deep purple, very minute crystals, glossy.
33	1	" , " , " .
34	1	Red-purple, no crystals, glossy.
35	1	Red-purple, no crystals, glossy.
36	1	Deep brown, metallic and aventurine separations glossy.
37	1	Gold-purple, very minute crystals, glossy.
38	1	Red-purple, no crystals, glossy.
39	01	Red-brown, no crystals, matt texture.
40	2	Black, no crystals, matt-texture. .
41	1	Deep brown, no crystals, semi-matt texture.
42	1	Deep brown-purple, no crystals.
43	1	Red-brown, no crystals, glossy.
44	1	" , " , " .
45	1	Red, no crystals, glossy.
46	1	Black-purple, no crystals, semi-glossy.
47	1	" , " , " .
48	1	" , " , " .

<u>Glaze</u>	<u>Cone</u>	<u>Description of glaze</u>
49	1	Black-purple, no crystals, semi-glossy.
50	1	Deep brown, no crystals, semi-glossy.
51	2	Black, no crystals, dull, under-fired.
52	2	Brown, " , " , " .
53	1	Red-brown, no crystals, dull, under-fired.
54	1	" , " , " , " .
55	1	Red, no crystals, matt texture.
56	1	" , " , " .

Discussion of Results of Glost Burn with Variable R O

Soda seems to be the member of the R O group which most assists crystallization. The glazes centered around the soda vertex of the pyramid all showed crystallization to a marked extent but the amount of crystallization diminished toward the other vertices. Potash was the next agent most conducive to crystallization, which is indicated by the formation of crystals in the trials all the way from the soda to the potash vertex. Lime and lead both seem to hinder the formation of crystals, probably because of the high viscosity of the glazes containing these R O members.

Lead and lime both made the glazes more refractory so that their maturing temperature is well above cone 1. Lime made the most refractory glaze of all.

The only effects noticed on the color was that lead gave the glazes a reddish-purple tinge which became more pronounced as the lead vertex was approached, becoming quite red-purple at the lead vertex.

Conclusions on the Effect of Soda, Lime, Potash and Lead on Aventurine Glazes.

From the above work, the following conclusions are deduced:

1. Soda aids the production of aventurine glazes more than any of the other R O members employed.
2. Lime gives the most refractory glaze of all R O members employed.
3. Potash is the second best agent in the production of Aventurine glazes and lead is next.
4. The color of the glazes is little effected by the R O members employed except by lead which gives a decided red-purple color to the glazes.
5. The influence of soda in the production of aventurine glazes in combination with other R O oxides is very strong. A little soda in the glaze makes a vast difference in the fusibility and the tendency to form crystals.

XI

General Conclusions.

The general conclusions drawn from this study of aventurine glazes are:-

1. For the production of aventurine glazes a slowly increasing and steadily oxidizing fire is necessary. The rate of cooling must be slow for the proper production of aventurine crystals.
2. An increase in SiO_2 requires an increase Fe_2O_3 to produce aventurine glazes. (Schurect)
3. An increase in the iron content increases the size and

number of crystals and also the refractoriness of the glaze.
(Schurecht)

4. An increase of Na_2O increases crystallization. Bromberg incorporated this conclusion in his work. (See page 7 of this thesis). The conclusion was verified in my own work on variations in the RO components.
5. Aventurine glazes may be formed in the presence of .2 mole of Al_2O_3 . (Bromberg, see page 7 of this thesis)
6. Aventurine crystals may be formed in the presence of CaO even when there is as much as .4 mole present. (Bromberg, see page 7 of this thesis)
7. Decreasing the lead increases crystallization and decreases the gloss. (Bromberg, see page 7 of this thesis) My work on variations in the RO members verified his statement.
8. Aventurine glazes are not restricted to any particular molecular or oxygen ratio, but come within the limits of good glazes. (Bromberg, see page 7 of this thesis)
9. A low iron oxide content (0.75 moles) together with a low boric acid content (1.25 moles) with high alumina (0.15 moles) and silica (7.00 moles) content produces the best goldstone effects. This is my own observation and agrees with the observation of Schurecht.
10. Crazeing occurs least in the areas of best crystallization. This is contrary to the behavior of most crystalline glazes but seems consistantly true with aventurines.
11. From the observations of Bromberg and from the conclusions of my own work on the variations in the RO contents, the order of beneficial effect upon crystallization of the RO members studied is as follows: 1. Soda. 2. Potash. 3. Lead. 4. Lime.

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